Technical Report Documentation Page

1. REPORT No.
CA-HY-MR-7080-1-72-45

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Synthesis Of Information On Highway Transportation And Air Quality

5. REPORT DATE
December 1972

6. PERFORMING ORGANIZATION
19701-953103-657080

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT No.
CA-HY-MR-7080-1-72-45

9. PERFORMING ORGANIZATION NAME AND ADDRESS
California Division of Highways
Materials and Research Department
5900 Folsom Boulevard
Sacramento, California 95819

10. WORK UNIT No.

11. CONTRACT OR GRANT No.
DOT-FH-11-7730

12. SPONSORING AGENCY NAME AND ADDRESS
U.S. Department of Transportation
Federal Highway Administration
Washington, D.C. 20590

13. TYPE OF REPORT & PERIOD COVERED
Final Report

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT
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Information is presented on the legal and medical aspects of air quality and on the relationships between a line source (the roadway) and air quality.

The role of the highway engineer in air quality is discussed in terms of planning, design, construction, maintenance and operation.

The importance of research on the subject is stressed.

17. KEYWORDS
Air quality, legal, medical, line source, highway engineer, transportation, research

18. No. OF PAGES:
41

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1972/FHWA-72-45.pdf

20. FILE NAME
72-45.pdf

TECHNICAL REPORT STANDARD TITLE PAGE

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17. KEY WORDS	18. DISTRIBUTION STATEMENT
Air quality, legal, medical, line source, highway engineer, transportation, research	Unlimited

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	41	

HMRT – 1242 (ORIG. 9/72)

State of California
Department of Public Works
Division of Highways
Materials and Research Department

SYNTHESIS OF INFORMATION ON HIGHWAY TRANSPORTATION AND AIR QUALITY

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December 1972

Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Office of Research
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ACKNOWLEDGMENT

The authors wish to acknowledge the contributions and advice of Dr. Howard Jongedyk, Office of Research, Environmental Design, and Control Division, Federal Highway Administration.

TABLE OF CONTENTS

INTRODUCTION

Recently Mr. William D. Ruckelshaus, Administrator, Environmental Protection Agency stated; (1) "Restoring the quality of our air environment is one of the most difficult and challenging tasks facing the nation today. We have a formidable job ahead of us in restoring air quality to a level compatible with health, comfort, convenience, and wise use of our resources. Smokestack controls and auto emissions controls - with present technology will not do the job alone. Substantial changes, for example, may have to be made in patterns of commutation by private car."

The highway engineer is faced with a series of complex problems in planning, designing, constructing, maintaining and operating a modern street or highway involved with the efficient movement of people and various materials. A recent problem of increasing magnitude is the possible change in air quality caused by such a project or system not only during construction, but in actual maintenance and operation. The study and solutions to the problem of air quality and other environmental concerns begins during initial planning and reaches a final stage in the design process.

Mr. J. A. Legarra, former State Highway Engineer, California Division of Highways, in a paper presented at the summer meeting of the Highway Research Board, Sacramento, California, August 1970 [2], summarized the position of a highway administrator as follows, "The Highway Administrator must take an active role in all types of environmental problems involving the highway system under his control. Air pollution is one of the key factors to be considered along with noise, water, and other forms of pollution. One of the most important present day duties of the highway administrator is to demonstrate his comprehension of air pollution problems and to respond by showing how this is translated into a specific highway proposal."

The purpose of this paper is to present a state-of-the-art outline on the relationship between air quality and highways. It is hoped that this outline will provide information that will aid highway engineers in understanding the problem.

AIR QUALITY

Air quality studies are concerned with the kind and amount of materials discharged into the atmosphere by man's activities. It is true that large quantities of materials that influence air quality are discharged into the air by natural activities, but over the ages these have not presented serious problems to the well being of plants and animals. It is unfortunate that man's activities have led to the building of concentrated complexes of industries and cities where large discharges of various materials occur in very limited areas. At times these areas have meteorological conditions that seriously delay the adequate mixing and dispersion of these materials with possible subsequent impairment of the air quality considered necessary for the health and welfare of man, animals, and plants.

Air quality is concerned with the term pollutant. To arrive at a definition one must look at the word contaminant. Scientists working in the field of air quality believe that any substance which is present in greater concentrations than it would be in normal clean air is a contaminant. When a contaminant is of such a nature that it is injurious to anything that is valued by man, it becomes a pollutant. However, the term pollutant is also applied to any substance which has been or could be a pollutant even though at innocuous concentrations.

Air pollution experts have divided up the sources into stationary and mobile. Stationary sources are those involved with all forms of industrial operations. Of direct concern to highway engineers are producers of highway materials involving aggregates, asphalt and portland cement mixtures and on-site contractor's operations. Also of concern are some maintenance operations that involve burning and dust formation.

Mobile sources include various types of vehicles that use the highway or city street. These include all that have some form of internal combustion engine wherein fuels of different composition such as gasoline or diesel oil are used as the energy source. Although the highway or street per se is not a source of air pollutants, the highway engineer is rapidly becoming involved in the concern over pollutants emitted by the vehicles operating on the roadway. Perhaps one should think of this aspect in the same manner as the present concept that the highway engineer plays a very important part in the safety of the motorist through the planning, design, and operation of the transportation system.

The following five primary pollutants are emitted in substantial amounts from various emission sources:

Carbon Monoxide	Sulfur Oxides
Hydrocarbons	Particulates
Nitrogen Oxides	

Table A shows the estimated nationwide man-made emissions of the five major pollutants for the year 1968. It will be noted that a substantial percentage of the carbon monoxide and hydrocarbons are derived from the motor vehicle. The nitrogen oxides are also contributed in definite quantities by the motor vehicle, but fuel combustion from stationary sources is also important. On the other hand sulfur oxides and particulates are almost entirely contributed by stationary sources such as industrial processes and power plants. Table B, "Ambient Air Quality Standards" indicates that particulates and sulfur oxides pose greater dangers for given concentrations and emission rates than the other three primary pollutants, especially carbon monoxide. It may be noted, therefore, that the contribution by motor vehicles toward poor national air quality is exaggerated if only the total weights of the primary pollutants are considered.

TABLE A

ESTIMATED NATIONWIDE EMISSIONS IN MILLIONS OF TONS FOR FIVE MAJOR POLLUTANTS IN 1968

Pollutant	Transportation		Fuel Combustion in Stationary Sources	Industrial Processes	Solid Waste Disposal	Other	Total	Percent of Total by Transportation	Percent of total by Motor Vehicle
Carbon Monoxide	64	59*	2	10	8	17	101	63	59
Hydro-Carbons	17	16	1	5	2	9	34	52	49
Nitrogen Oxides	8	7	10	0.2	1	2	21	39	35
Particulates	1+	1-	9	8	1	10	29	4	3
Sulfur Oxides	0.8	0.3	24	7	0.1	1	33	3	1

Source: Nationwide Inventory of Air Pollutant Emissions 1968, U. S. Department of Health, Education and Welfare, Public Health Service, Environmental Health Service, National Air Pollution Control Administration, Raleigh, North Carolina, August 1970

*Motor Vehicles

One should be aware of the differences in importance of these pollutants in various areas of the United States. As an example, in the Los Angeles area, the emissions from motor vehicles of carbon monoxide, hydrocarbons, nitrogen oxides, and particulates are a large percentage of the total. On the other hand, in areas where concentrations of industrial and thermal power plants exist, particularly sulfur oxides, but also nitrogen oxides and particulates from stationary sources, are of greatest importance.

In certain areas where meteorological and topographical constraints are present, one may encounter secondary reactions. These reactions lead to the formation of so-called photochemical "smog" [3]. The compounds in "smog" may produce undesirable health effects in man and animals and damage to certain types of plants of economic importance.

Chemicals involved in the formation of photochemical smog include hydrocarbons, nitrogen oxides commonly from the automobile exhaust and stationary sources and atmospheric oxygen. A "mixing bowl" or basin such as the Los Angeles Area must be provided with meteorological and topographical constraints which serve to limit the horizontal and vertical dispersion of the primary pollutants. All that remains is to add ultraviolet radiation from the sun on clear days and the reactions lead to the formation of photochemical smog. The reactions are very complex due to the great complexity of the hydrocarbons.

In summary, we have primary emissions partly from man's activities and secondary materials generated under certain circumstances from certain of the primary materials. Both primary and secondary materials may have adverse effects and must be considered in assessing the problem of air pollution.

In order to control air quality, each state has been divided into Regions termed in this report "Basins" based on common meteorological conditions. As an example, Figure 1 shows the California basins. Each basin may contain a number of cities, counties, and parts of more than one state. Some states and now the Federal Government have issued Ambient Air Quality Standards which are common to all Air Basins. The Ambient Air Quality Standards applicable in California are compared with the recently issued Federal Air Quality Standards in Table B. These standards are for the purpose of protecting the health and public welfare of the people. The Federal Standards are of great importance to the highway engineer since laws passed by Congress require each state to provide an acceptable Implementation Plan to the Federal Environmental Protection Agency. Such a plan shall detail methods for the attainment of ambient air quality equal to or better than the Air Quality Standards in each basin on or before January 1, 1975, or at the latest January 1, 1977. As noted by Mr. Ruckelshaus (1), with reference to meeting such standards in certain basins of the United States, "Substantial Changes, for example, may have to be made in patterns of commutation by private car."

O R E G O N
North Coast
San Francisco Bay Area
SAN FRANCISCO
North Central Coast
South Central Coast
South Coast
San Diego
San Joaquin Valley
Southeast Desert
Lake Tahoe
Bakersfield
N E V A D A
A R I Z O N A
M E X I C O
P A C I F I C O C E A N
CALIFORNIA AIR BASINS
State of California
The Resources Agency
AIR RESOURCES BOARD

Figure 1

Table B

AMBIENT AIR QUALITY STANDARDS
APPLICABLE IN CALIFORNIA

Pollutant	Averaging Time	California Standards		Federal Standards[4]		
		Concentration[7]	Method[1]	Primary[2,7]	Secondary[3,7]	Method[5]
Photochemical Oxidants (Corrected for NO_2)	1 hour	0.10 ppm (200 μg/m³)	Neutral Buffered KI	160 μg/m³ [8] (0.08 ppm)	Same as Primary Std.	Chemiluminescent Method
Carbon Monoxide	12 hours	10 ppm (11 mg/m³)	Non-Dispersive Infrared Spectroscopy	---	Same as Primary Standards	Non-Dispersive Infrared Spectroscopy
	8 hours	---		10 mg/m³ (9 ppm)		
	1 hour	40 ppm (46 mg/m³)		40 mg/m³ (35 ppm)		
Nitrogen Dioxide	Annual Average	---	Saltzman Method	100 μg/m³ (0.05 ppm)	Same as Primary Standard	Colorimetric Method Using NaOH
	1 hour	0.25 ppm (470 μg/m³)		---		
Sulfur Dioxide	Annual Average	---	Conductimetric Method	80 μg/m³ (.03 ppm)	60 μg/m³ (0.02 ppm)	Pararosaniline Method
	24 hours	0.04 ppm (105 μg/m³)		365 μg/m³ (0.14 ppm)	260 μg/m³ (0.10 ppm)	
	3 hours	---		---	1300 μg/m³ (0.5 ppm)	
	1 hour	0.5 ppm (1310 μg/m³)		---	---	
Suspended Particulate Matter	Annual Geometric Mean	60 μg/m³	High Volume Sampling	75 μg/m³	60 μg/m³	High Volume Sampling
	24 hours	100 μg/m³		260 μg/m³	150 μg/m³	
Lead (Particulate)	30 Day Average	1.5 μg/m³	High Volume Sampling, Dithizone Method	---	---	---
Hydrogen Sulfide	1 hour	0.03 ppm (42 μg/m³)	Cadmium Hydroxide STRactan Method	---	---	---
Hydrocarbons (Corrected for Methane)	3 hours (6-9 a.m.)	---	---	160 μg/m³ (0.24 ppm)	Same as Primary Standard	Flame Ionization Detection Using Gas Chromatography
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility[6] to 10 miles when the relative humidity is less than 70%		---	---	---

NOTES:

1. Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.

2. National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency (EPA).

3. National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after implementation plan is approved by the EPA.

4. Federal standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year.

5. Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" to be approved by the EPA.

6. Prevailing visibility is defined as the greatest visibility which is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors.

7. Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25° C and a reference pressure of 760 mm of mercury.

8. Corrected for SO_2 in addition to NO_2.

A study of the Federal Standards reveals two sets of requirements known as primary and secondary. Note that the primary standards are for the purpose of protecting the public health with an adequate margin of safety while the secondary standard is to "protect the public welfare from any known or anticipated adverse effects of a pollutant". We note that under these definitions the standards may be considered all encompassing for ambient air.

An excellent discussion on the Federal Standards is contained in (4). The reference should be carefully studied since it presents a critical review and a reply by members of the Environmental Protection Agency concerned with the research and study leading to the present requirements. The difficulties of writing air quality standards based on the available evidence is well brought out in the review paper and the discussion.

The Federal Implementation Plan will be discussed in more detail in a subsequent portion of this paper. For now, it is important to note that each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency. Further, Section 109J of the Federal Highway Act states, in effect, that the construction of Federal-aid highways must be consistent with any approved plan for the implementation of federal air quality standards. Forthcoming Federal instructions will call for discussion in the Environmental Impact Statement of consistency between the implementation plans and any highway project. Such a discussion must be based on data and conclusions presented in the Quantitative Air Quality Report.

LEGAL ASPECTS

It is important to understand the legal background for environmental studies since public law, in many cases, dictates the manner in which certain aspects of an Air Quality study must be performed and, in general, dictates the questions which must be answered.

The first major law affecting the work of the Highway Engineer with regard to air pollution was the National Environmental Policy Act of 1969. This act created the Council on Environmental Quality. Implementation of this act by the Federal Highway Administration occurred in the form of policy and procedure memorandum (PPM) 90-1. The purpose of the PPM is to provide guidelines to highway departments to assure that the human environment is carefully considered and national environmental goals are met when developing federally financed highway improvements. This PPM reiterates that portion of the law requiring an environmental impact statement for each federally financed project.

Two other important federal laws were enacted in 1970. The first of these, the Clean Air Amendments of 1970, empowered the Environmental Protection Agency (EPA), previously established by executive reorganization, to establish national ambient air quality standards and to require each state to submit a plan providing for implementation, maintenance, and enforcement of such standard in each air quality control region within such state. These plans, discussed earlier, are termed implementation plans.

The final national law, the Federal Aid Highway Act of 1970 provides for the establishment of general guidelines to assure that possible adverse economic, social, and environmental effects relating to any proposed project on any federal aid system have been fully considered in developing the project. That act also calls for the development of guidelines to assure that highways constructed pursuant to that act are consistent with any approved plans for the implementation of any ambient air quality standard or any air quality control medium designated by the Clean Air Act.

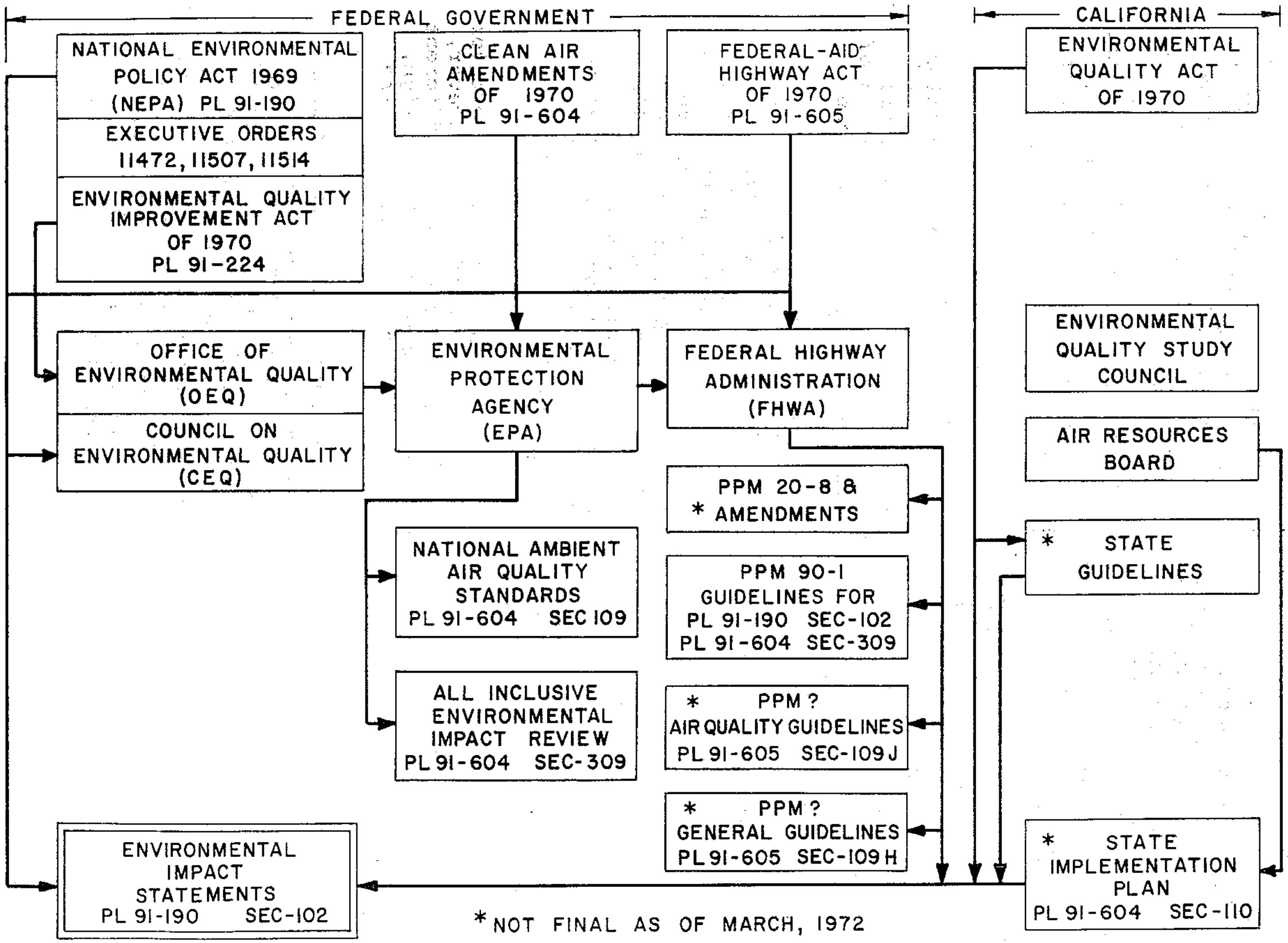
Figure 2 illustrates the general relationship between these laws and the bibliography, references (5 through 14), lists references for further reading in the area of environmental law.

MEDICAL ASPECTS

The medical aspects of the various emissions are very complex and a great deal of research has been completed on the subject. In addition, studies of many different kinds are scheduled to be performed in the future. A continuing problem is the consideration of short and long range effects of the individual emissions, and of more recent concern is the indication that some of the pollutants may have a more serious effect on health when acting in combination than alone.

At the present time air quality standards are developed to protect those people who are especially susceptible to the effects of air pollutants. It has been found by extensive studies that these susceptible individuals are primarily the very old and the very young, those with cardiac insufficiencies and anemia, and respiratory cripples.

The highway engineer cannot be expected to be familiar with the complex problems involving the effects of the various emissions on men, animals and plants. However, he should be cognizant that the primary and secondary federal standards are based on



*NOT FINAL AS OF MARCH, 1972

Figure 2 MAJOR LAWS AND REGULATIONS GOVERNING AIR QUALITY IMPACT STUDIES FOR HIGHWAY PROJECTS substantial amounts of evidence, some of which is controversial (4). For this reason we have listed references to a series of air quality criteria which should be studied for details on many aspects of each pollutant including medical details (15 through 20). These manuals are an excellent source of information and should be carefully studied by those in a highway department who are directly concerned with the preparation of air quality reports. Also Part III of reference 21 provides a series of well written papers on various effects, such as human health, biologic effects, vegetation, and materials.

THE ROADWAY (LINE SOURCE) AND AIR QUALITY

The primary emissions from the spark ignition internal combustion engine are: carbon monoxide (CO), hydrocarbons (Hc), oxides of nitrogen (NOx) and particulates of which the lead compounds are most important. Two of these primary gaseous emissions, oxides of nitrogen and hydrocarbons, react in the presence of ultraviolet light to form secondary materials.

The route, whether it be a city street or a modern freeway, is a line source of emissions from the traffic using that roadway. The microenvironment (microscale analysis) is involved with the mixing and dispersion of the emissions within the immediate area adjacent to the line source, Figure 3. This area is stated to be the corridor extending some distance on each side of the line source. The boundaries of the corridor are defined by that line which shows the reduction of emissions from the line source to ambient levels. This distance upwind and downwind from the line source may vary from day to day because of changes in micro-meteorological conditions and may vary along the line source depending on topography.

In most cases only primary emissions are considered in the corridor since photochemical changes require some period of time. However, when winds blow parallel to the line source there may be sufficient time for some photochemical reaction to take place. Also design, topography, and micrometeorological conditions all influence the degree of potential photochemical change.

The mesoscale involves all of the area outside the corridor where there are effects either from the primary emissions from the specified line source or the photochemical products derived from these emissions, Figure 4. The mesoscale meteorologically is of the order of two to two hundred miles and encompasses areas of community to air "basin" in size. This is a very difficult area to delineate since the emission load from the line source becomes mixed downwind with all other sources from within and outside the area. The specific contribution of the line source emissions to photochemical reactions downwind is virtually impossible to determine at present because of the lack of suitably validated

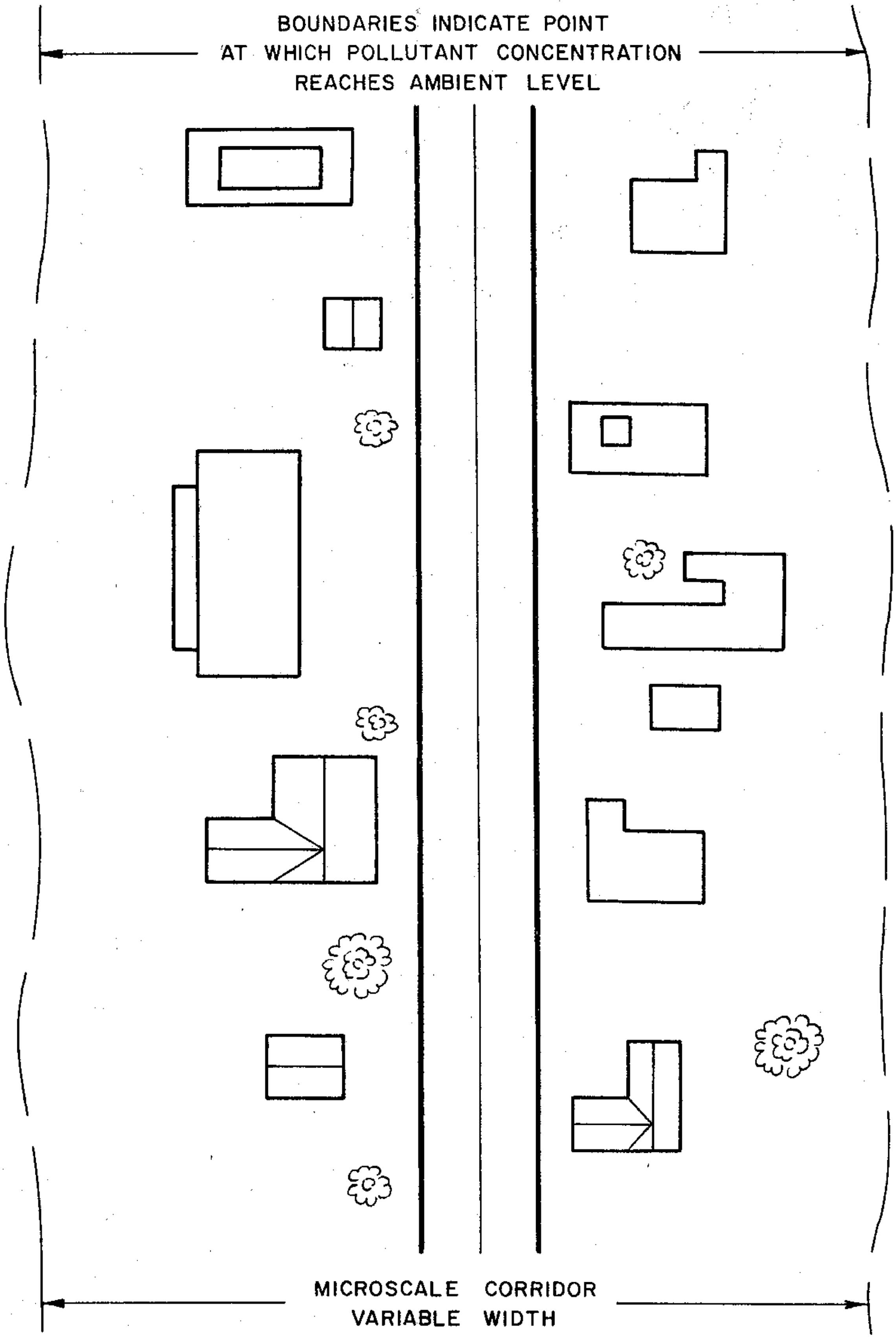


Figure 3 MICROSCALE ANALYSIS

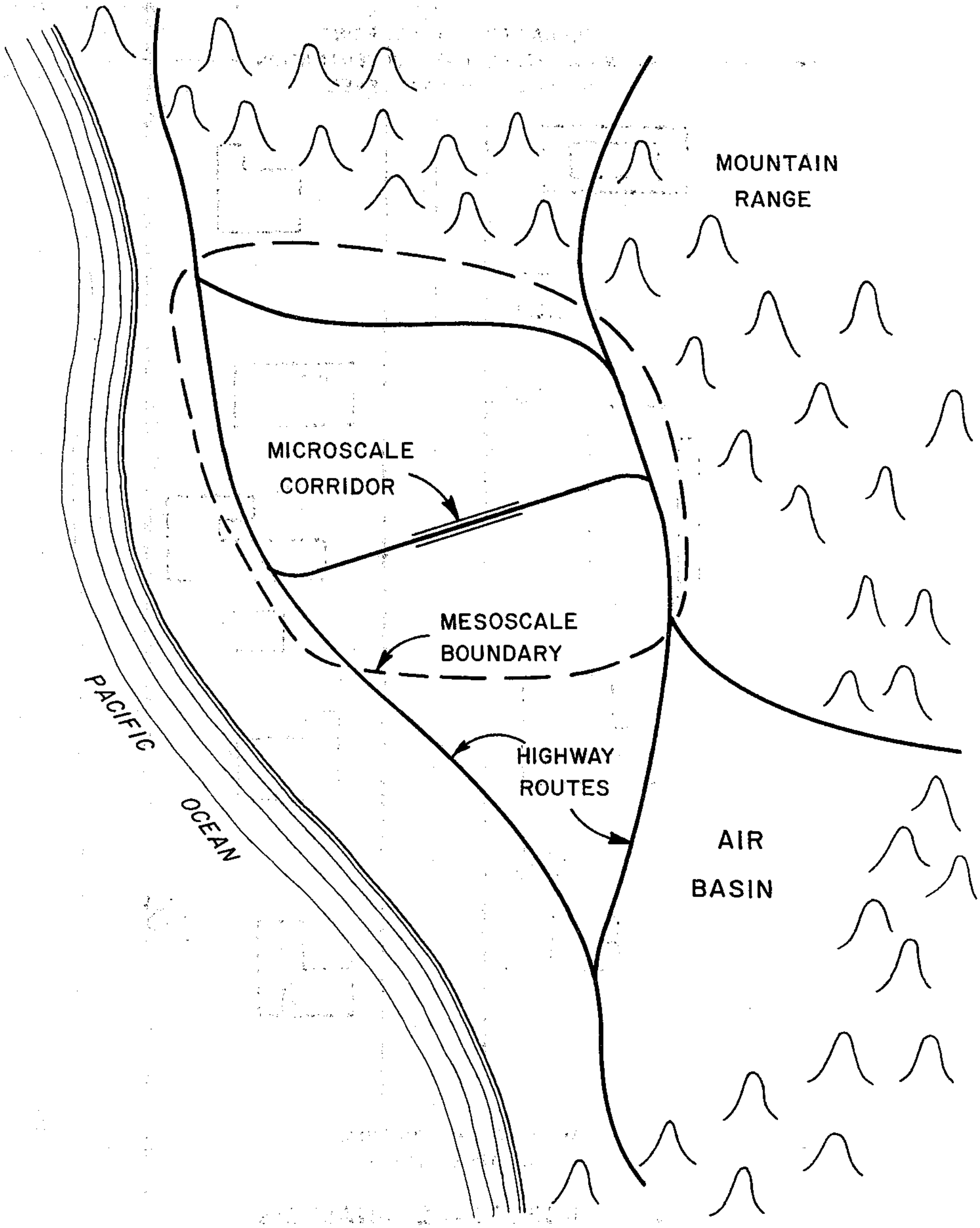


Figure 4 MESOSCALE ANALYSIS

photochemical models. Currently, the best practical solution to this problem is to assume that the mesoenvironment encompasses that area in which there are sufficient modifications in the surface traffic pattern caused by the construction of the new facility.

The amount of vehicle emissions from a line source is influenced by:

1. Volume of traffic
2. Vehicle mix in terms of model year
3. Vehicle operational characteristics

The influence of highway vehicle emissions on people, animals, and plants within the corridor (microscale) is governed by:

1. Mechanical mixing by traffic

2. Micrometeorology

3. Natural topography of the area adjacent to the roadway

4. Right of way widths and distance to receptor

5. Highway geometric configuration

6. Building configuration and kind of occupancy near the alignment

7. Patterns of agricultural land use within the corridor

8. Upwind pollutant concentrations (background levels)

The influence of highway vehicle emissions on the people, animals, and plants within the immediate area beyond the corridor and within the basin (mesoscale) is influenced by:

1. Mesometeorology

2. Large scale topography

3. Distribution of sensitive receptors

4. Patterns of agricultural land use

5. Existing pollutant levels

Traffic volume, mix of vehicles in terms of model year, and vehicle operational characteristics are important factors influencing the amount of emissions. Older, uncontrolled vehicles emit a greater amount of emissions than newer vehicles having emission controls. As an example, the following compares typical uncontrolled vehicles and the Federal requirements for the 1975 and 1976 controlled vehicles.

PASSENGER CAR EXHAUST EMISSIONS
GRAMS/MILE

Pollutant	Typical Uncontrolled Vehicle	Federal Requirements* 1975	1976
Carbon monoxide	80	3.4	3.4
Hydrocarbons	11	0.41	0.41
Nitrogen Oxides	5.5	3.0	0.4

*Federal Register XXXVI, No. 228, Nov. 25, 1971, p 22452

The importance of the development of low cost control devices for older model cars (pre-1966) is apparent when one considers that currently approximately 80% of the Nation's automobiles do not have any type of pollution control device or system.

Another very important factor influencing total emissions from a line source are the vehicle operating characteristics. The operating modes are known as idle, acceleration, deceleration, and cruise.

The table below lists the percentage of each emission emitted per average mile traveled for each mode of operation. This is based on the following; "When the distribution of time for each of the operating modes developed in field survey work is combined with the emissions per vehicle mile of travel, the percentage emission value per average vehicle mile for each mode of the 11 mode cycle can be established." The importance of maintaining a cruise mode of operation is brought out by a study of this table. Therefore, features of the roadway which tend to reduce the use of deceleration and acceleration modes, such as reduced grades, ample radius curves, reduced congestion, etc., will tend to lower emissions.

PERCENTAGE OF CONTAMINANT EMITTED IN EACH
MODE PER AVERAGE MILE TRAVELED

Operation Mode	Gross Hydrocarbons	Carbon Monoxide	Nitrogen Oxide
Idle	5.9%	7.5%	0.03%
Cruise	14.1%	14.3%	21.40%
Acceleration	56.2%	62.2%	78.50%
Deceleration	23.7%	16.1%	0.17%

Source: Rose, A. H., and Smith, R.
"A Direct Measurement Technique for Automobile Exhaust"
Archives of Environmental Health, Vol. 5, p 95, 1962.

Emissions are also influenced by the average route speed of the vehicle. The average route speed takes into account the variations in speed caused by acceleration, deceleration, and idle modes in average city street driving. Such changes are mainly caused by traffic signals and vehicle congestion. Thus the average route speed on a city street may be 15-20 miles/hour while on an expressway or freeway, with the majority of time being in the cruise mode, the average route speed may be in the range of 45-55 miles/hour. Figures 5 and 6 show reductions in carbon monoxide and hydrocarbons with increase in average route speed.

However, this reduction does not apply across the board, since nitrogen oxide and lead emissions increase with higher engine speeds.

The studies on the relation of emissions to route speed are mainly based on the work of Rose [22] which was developed using 1963 and earlier model year vehicles with no exhaust emission controls. In a recent study [23] Beaton, et al state, "H. W. Sigworth of the Environmental Protection Agency indicates that Rose's work (shape of curves) is probably valid for vehicles without emission controls, but is probably less valid though still roughly applicable for pre-1975 vehicles with exhaust emission controls. Sigworth points out because of the radically different emission characteristics of 1975 and later vehicles, that he expects the curves would have little applicability to them"[23]. It is, therefore, expected that 1975 and later models will be essentially "pollution free" and emissions from such vehicles should be relatively independent of route speed. However, it should be stressed that for some years beyond 1975 the mix of cars on roadways will continue to have substantial numbers of uncontrolled and partially controlled vehicles. Therefore, the importance of the influence of route speed on carbon monoxide and hydrocarbon emissions cannot be overstressed with respect to meeting Federal Air Quality Standards by January 1, 1975.

All of this discussion is also directly related to the exposure of the driver and occupants of the vehicle to pollutants. City street driving is generally involved with marked changes in speed of the vehicles including all four of the operating modes. Vehicles stopping at signals are closely grouped not only in their own lane but also in adjacent lanes. During the deceleration for stop signals the waiting idle period and the rapid acceleration following clearance, the emissions are very high per vehicle.

On the other hand the increase in route speed through use of more unrestricted roadways lowers emissions and allows operation in the cruise mode for a substantial part of the trip. Further, such increase in route speed accelerates the mixing of all the pollutants and prevents zones of intense concentration from forming. Studies indicate the presence of a "mixing cell" within the roadway prism where turbulent action of high speed vehicles actively promotes mixing and the lowering of the pollutant concentration to a common figure for the cell. Such action lowers the level of emissions reaching the occupants of the vehicles. Entrainment of pollutants by winds are reduced by slow moving or idling vehicles. In this

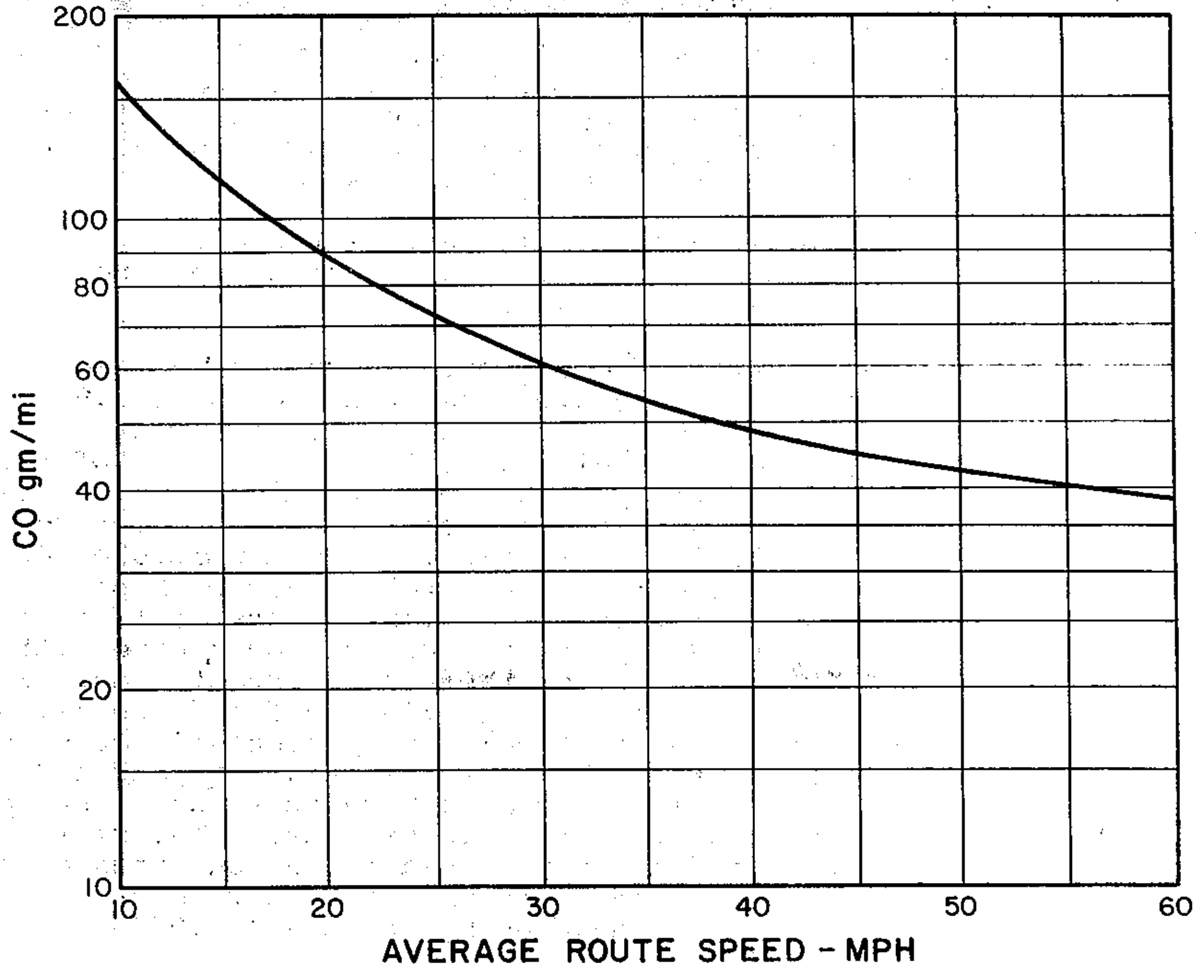


Figure 5 CARBON MONOXIDE EMISSIONS VS AVERAGE ROUTE SPEED FOR UNCONTROLLED VEHICLES-PRE 1966 MODELS

SOURCE:
ROSE, A.H., Jr., SMITH, R., McMichael, W.F. AND KRUSE, R.E., (REFERENCE 22)
"COMPARISON OF AUTO EXHAUST EMISSION IN TWO MAJOR CITIES"
JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION, VOL.15, NO.8, 1965.

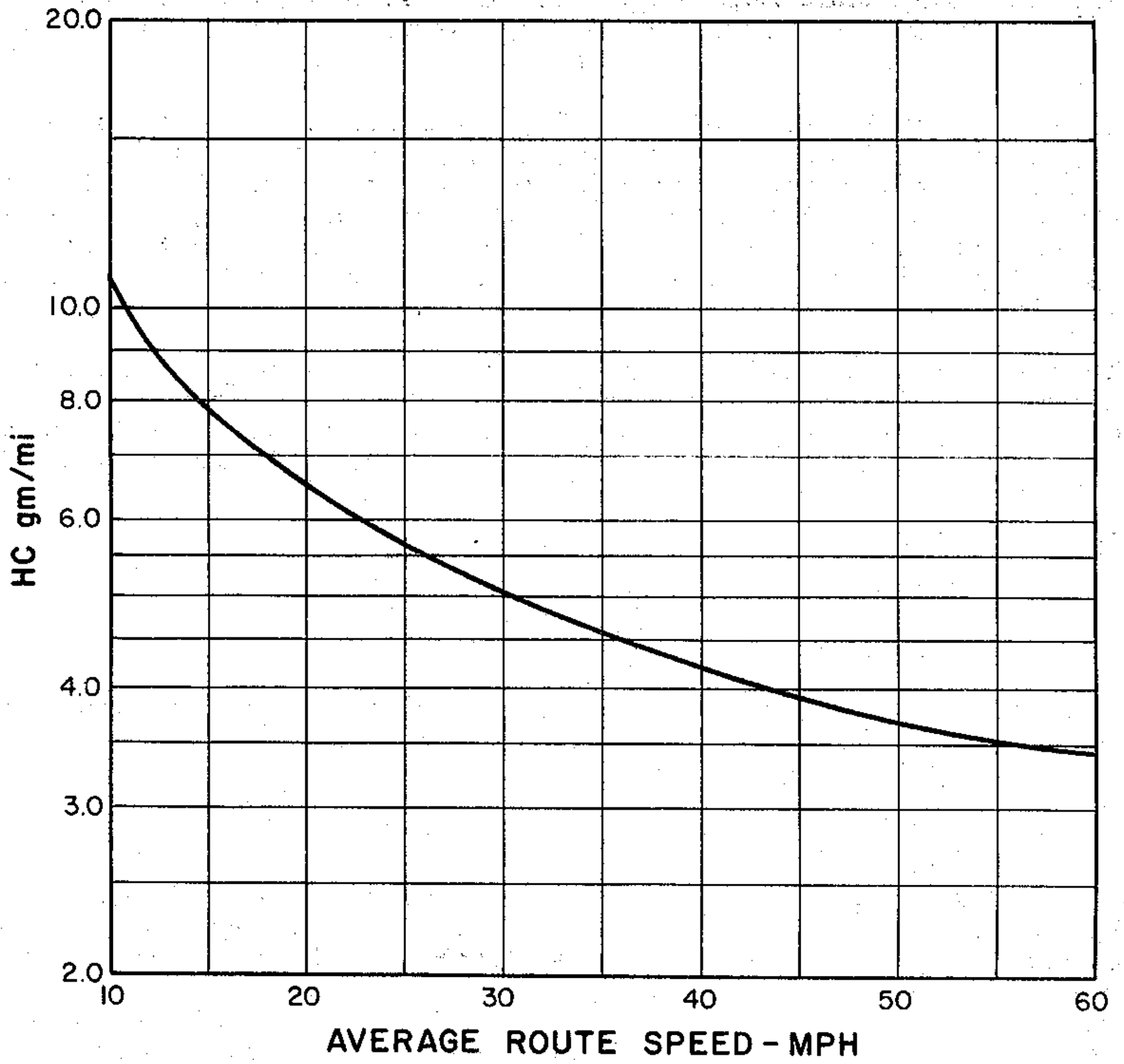


Figure 6 HYDROCARBON EMISSIONS VS AVERAGE ROUTE SPEED FOR UNCONTROLLED VEHICLES-PRE 1966 MODELS

SOURCE:
ROSE, A.H.,Jr., SMITH, R., McMichael, W.F. AND KRUSE, R.E., (REFERENCE 22) "COMPARISON OF AUTO. EXHAUST EMISSIONS IN TWO MAJOR CITIES" JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION, VOL. 15, NO. 8, 1965.

connection it cannot be overstressed that congestion leading to stop and go operations on any roadway will not only increase the emission load that must be dispersed but also will increase the concentrations of emissions for occupants of the vehicles and nearby locations.

The manual by Beaton, et al [23] considers the use of emission factors for calculation of the tonnage of emissions from a given volume of traffic operating at average route speed. This information is required for an assessment of the mixing and dispersion of the emissions from the line source and for an estimate of the mesoscale pollution levels in the immediate air basin surrounding the line source.

The total load of emissions from vehicles using the roadway must be effectively mixed and dispersed so that pollutant levels fall to existing or background levels as soon as possible downwind from the line source. (microscale or corridor analysis). The following factors influence the mixing and dispersion operation with the corridor.

1. Traffic action within the "mixing cell"

2. Micrometeorology

3. Natural topography of the immediate area around the roadway

4. Building configuration

5. Highway geometric configuration

A. Q. Eschenroeder [24], in an outstanding paper, first introduced the concept of the "mixing cell". In this concept the turbulence generated by moving vehicles especially at higher speeds mixes the emissions to produce an average concentration within the so-called "mixing cell". The boundaries of the cell have still to be more precisely defined, but the first validation studies clearly indicate the importance of the mixing cell regime in reducing concentrations to an average condition within the roadway prism [25].

The second and all important factor is the micrometeorology of the line source. In other words a clear understanding of the meteorological conditions existing along the corridor is essential in predicting the dispersion of the emissions. We cannot overstress the importance of on line observations with sensitive meteorological instrumentation in order to characterize all essential parameters [26].

The natural topography of the immediate area will influence wind flow patterns and, therefore, the transport of emissions downwind. Certain topographic features may influence the concentration of air contaminants in certain areas. Meteorological data are necessary to allow construction of wind streamlines which are influenced by the topography.

Building configuration downwind of the line source may produce aerodynamic effects leading to distortion in wind direction with subsequent changes in emission concentrations. Highway configurations such as fills crossing canyons, etc., will influence wind direction and flow of emissions. Other highway designs such as depressed and elevated structures produce different dispersion patterns for emissions and in the future it is possible that certain designs which aid in dispersion or retention within the right of way of pollutants may be required in critical areas where topographical and meteorological conditions lead to a concentration of air contaminants on or near roadways.

A number of studies have been performed on the dispersion of emissions within the corridor. However, most of these lack sufficient meteorological data and not enough observations under varying wind conditions are noted. We note the following, stressing the great need for further and more complete studies:

Most of the studies have used carbon monoxide as a tracer gas, but some studies are also reported for others such as hydrocarbons. All of the gases from the exhaust disperse in the same general manner. Reed and Barrett [27] showed that ground level concentrations of smoke downwind from a roadway edge decreased sharply relative to 6'-9' from edge of road:

35% at 30'
66% at 60'
85% at 120'
∿100% at 150-180'

Studies as far back as 1956 by the Air Pollution Foundation [28] indicate a very rapid dilution of hydrocarbons. As an example, one car in a cruise state can emit from 250 to 550 ppm of hydrocarbons from the exhaust. Typical data on dispersion, from this report, is as follows:

Location	Hydrocarbons-ppm
10 ft. from curb of roadway	1.40
35 ft. from curb	1.34
60 ft. from curb	1.21

Confirmation of this work is stated by J. A. Maga, presently executive officer of the California Air Resources Board [29], "The concentration of carbon monoxide in traffic when compared to that in the exhaust indicates that exhaust emissions from moving automobiles are <u>immediately</u> diluted several hundred fold." It should be noted that this is within the traffic lanes themselves.

In other words, in the region that forms the inner core there is very rapid dispersion of emissions caused mainly by the movement of the vehicles. The higher the speed the more turbulent the mixing action generated by the vehicle. Freeway driving permits a maximum of such action because of the high route speed. Such action coupled with crosswinds is responsible for the rapid drop in concentration of emissions on each side of the freeway.

Bryan and Taylor [30] have reported that the concentration of contaminants at a monitoring station located 150' from the traffic lanes of a heavily used freeway were about the same as those from other monitoring stations in Los Angeles.

Brice and Roesler [31] made an investigation in a number of large cities on the exposure to carbon monoxide of occupants of vehicles moving in heavy traffic. In connection with this study, Brice and Roesler made a comparison of the differences in carbon monoxide and hydrocarbon concentrations near the driver in traffic, and at continuous air monitoring program (CAMP) stations located in the downtown areas of each city. These stations were positioned 50 to 70 feet from the street with the sample intake about 15 feet above the ground. The following table presents their findings:

City	Average Carbon Monoxide PPM		Ratio	Average Hydrocarbons PPM		Ratio
	in Traffic	CAMP Site		in Traffic	CAMP Site	
Cincinnati	21	3.1	6.8	5.7	2.3	2.5
Denver	40	17	2.4	9.6	5.6	1.7
St. Louis	36	17	2.1	9.3	3.5	2.7
Washington	25	5.3	4.7	6.2	2.7	2.3
Chicago	37	29	1.3	4.8	3.4	1.4

The results clearly indicate the effect of rapid dispersion between the driver's location and the area adjacent to the city street, even though the downtown route was "boxed" in by tall buildings which reduces ventilation regardless of wind direction.

In a recent study by Colucci and Begeman [32] on carbon monoxide in Detroit, New York, and Los Angeles air, the following sampling of results is given:

Los Angeles Site	Area Type	Approximate Distance from Nearest Traffic Feet	Carbon Monoxide PPM
Pico Blvd.	Commercial	12	9
Harbor-Santa Monica Freeway Interchange	Freeway	15	8
Santa Monica	Car Storage Lot Santa Monica Blvd.	18	5

A comprehensive final report [33] on a study of air pollution aspects of various roadway configurations in New York City presents data on carbon monoxide concentrations both vertically and horizontally from different roadway sections. The dispersion of carbon monoxide from a number of these roadway configurations are shown in Figs. 7 through 12. This report presents information from the most comprehensive study yet undertaken on the subject of dispersion of emissions from different roadway configurations. The report should be consulted since ten urban roadway configurations were studied. Generally, it was noted that:

1. Peak hourly carbon monoxide concentration at these highway sites:

   (a) Greatly exceeded ambient air quality standards on the roadway,

   (b) Were always less than ambient air quality standards at nearest receptor points near the highway. This was especially true for a deep cut, an at grade section, a shallow cut and a viaduct section.

2. Peak hourly and average concentrations were highest for locations in or near points of confined or restricted air such as semi-enclosed highway points and tunnels.

In preliminary studies [34] the California Division of Highways has determined the dispersion of emissions (carbon monoxide) from Cut and Fill Sections, Figures 13 and 14.

The evidence presented herein indicates in general a rapid dispersion of emissions occurs from roadway systems, and that concentrations of emissions approach background levels at relatively short distances from the traffic lanes of highways or freeways.

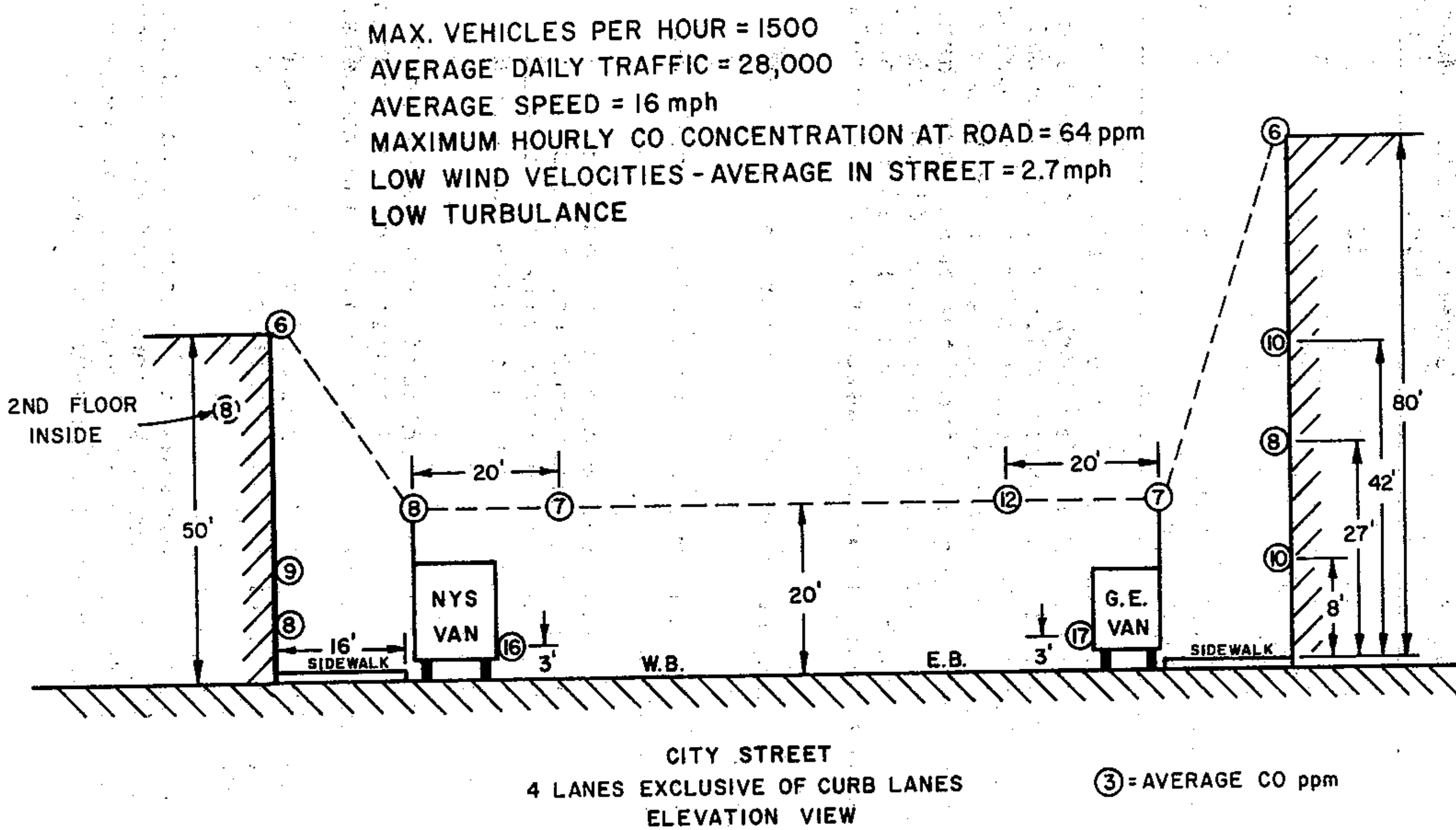


Figure 7 DISPERSION OF CARBON MONOXIDE FROM A CITY STREET
CANAL STREET BETWEEN CHURCH AND MERCER
NEW YORK STUDY

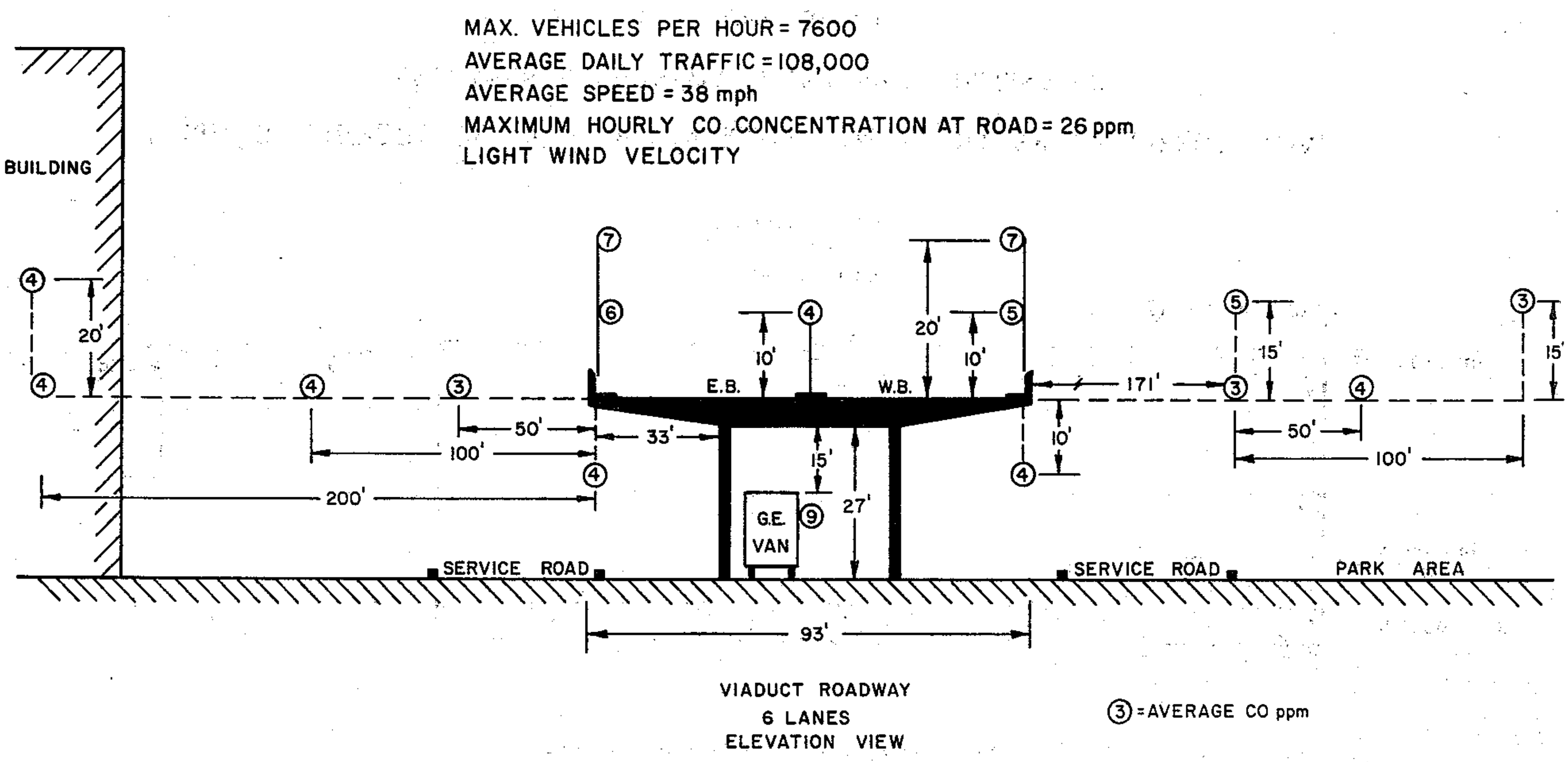


Figure 8 DISPERSION OF CARBON MONOXIDE FROM VIADUCT SECTION
BROOKLYN QUEEN EXPRESSWAY AT PARK AND NAVY STREETS
NEW YORK STUDY

MAX. VEHICLES PER HOUR = 4700
AVERAGE DAILY TRAFFIC = 55,000
AVERAGE SPEED = 48 mph
MAXIMUM HOURLY CO CONCENTRATION AT ROAD = 34 ppm
AVERAGE WIND SPEED = 8.1 mph

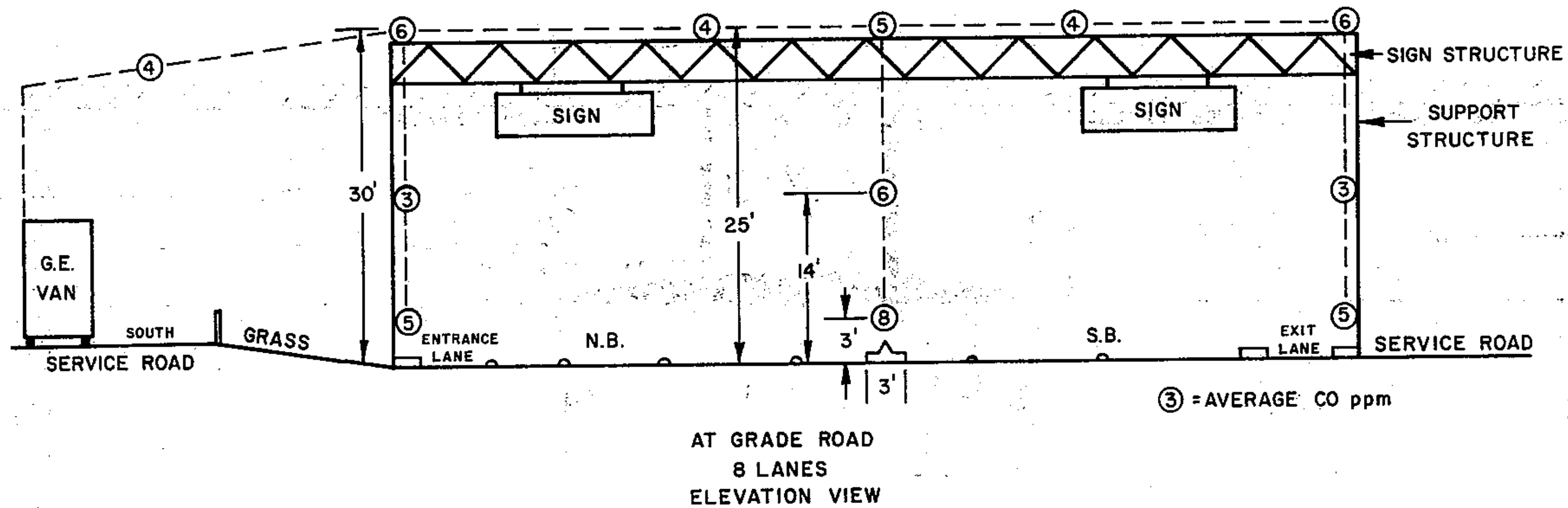


Figure 9 DISPERSION OF CARBON MONOXIDE FROM AN AT GRADE ROAD

BRUCKNER EXPRESSWAY NEAR WHITE PLAINS ROAD

NEW YORK STUDY

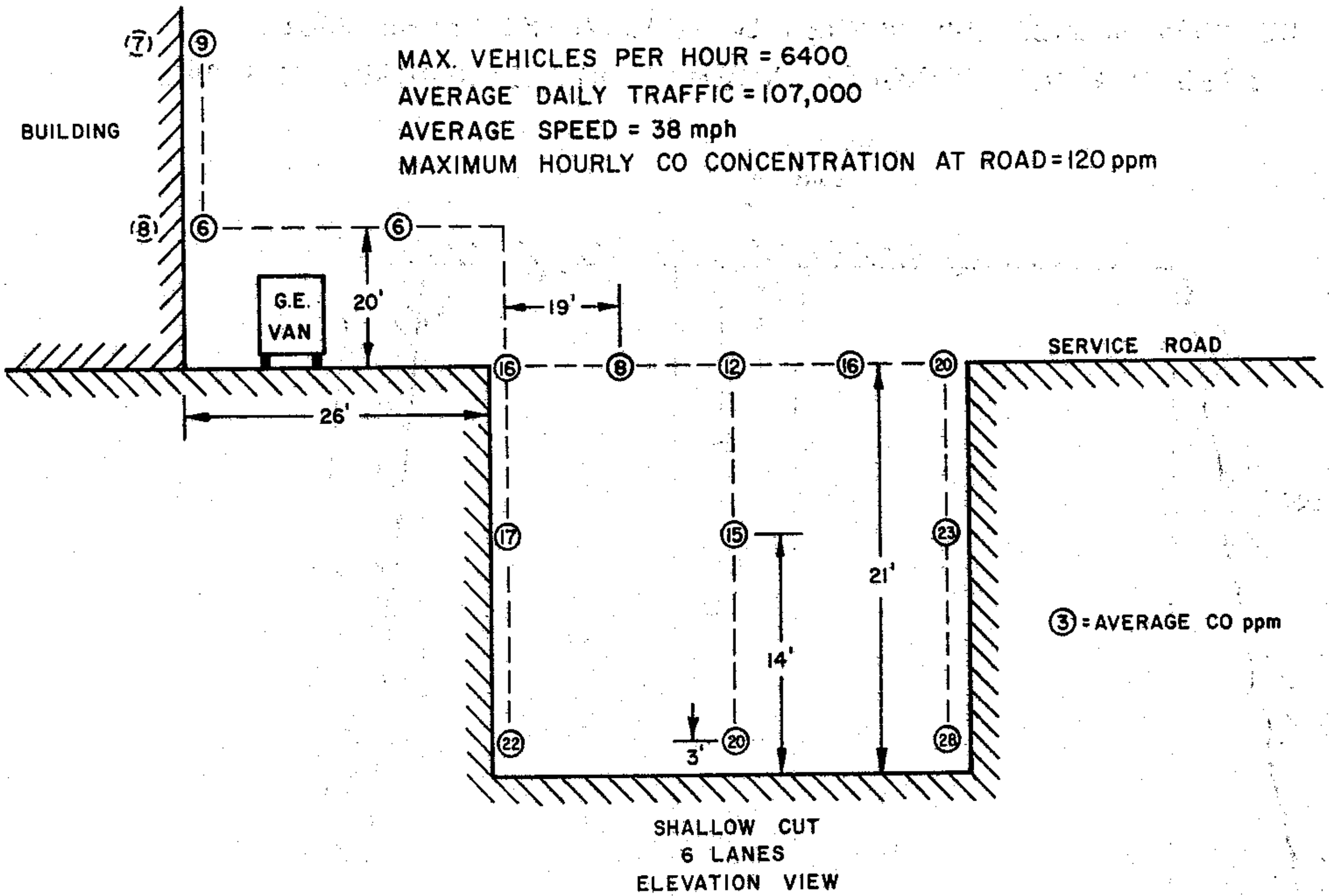


Figure 10 DISPERSION OF CARBON MONOXIDE FROM A SHALLOW CUT
BROOKLYN QUEENS EXPRESSWAY AT HICKS STREET
NEW YORK STUDY

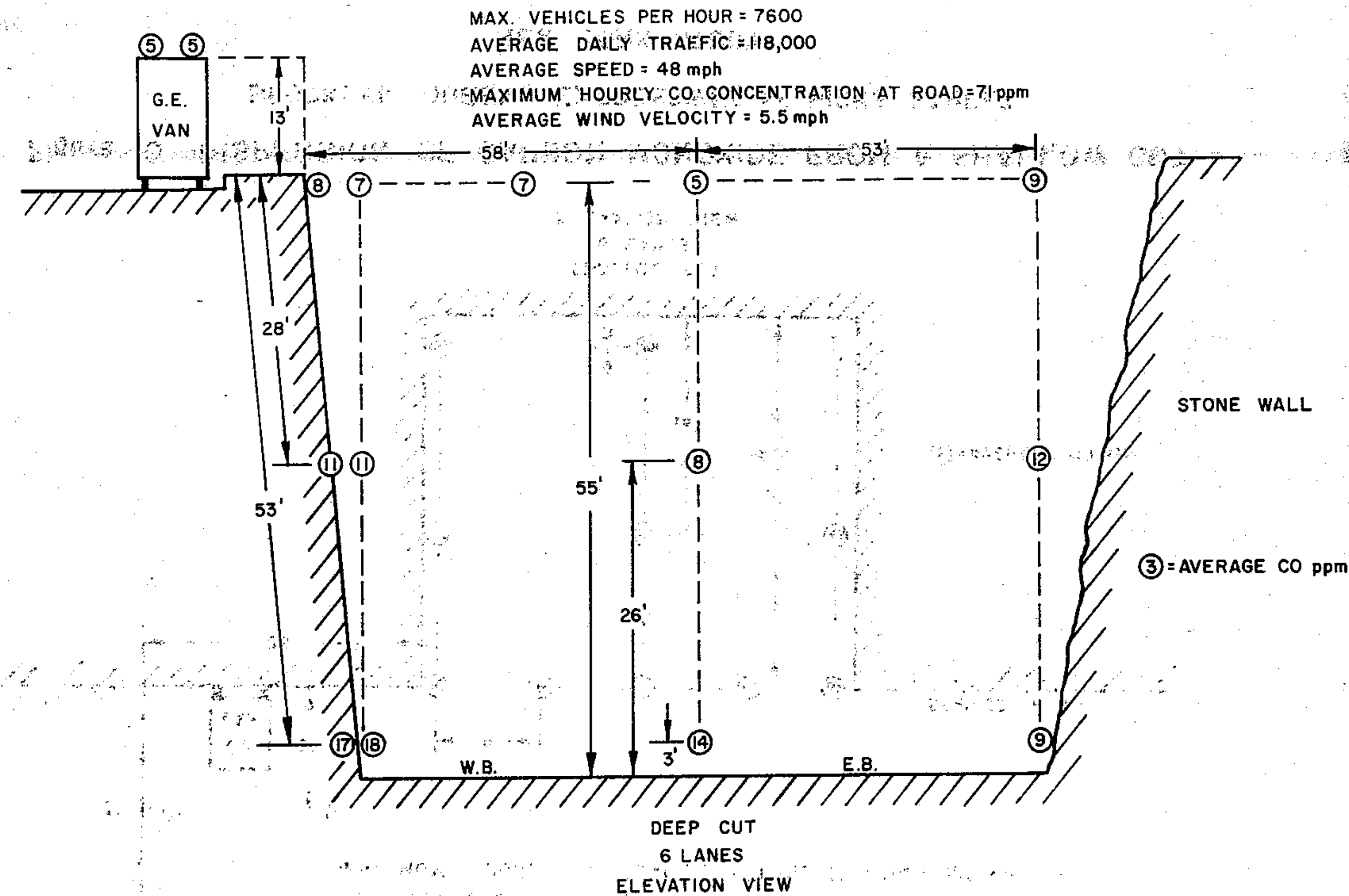


Figure 11 DISPERSION OF CARBON MONOXIDE FROM A DEEP CUT
CROSS BRONX EXPRESSWAY AT NELSON AND JESSUP AVENUES
NEW YORK STUDY

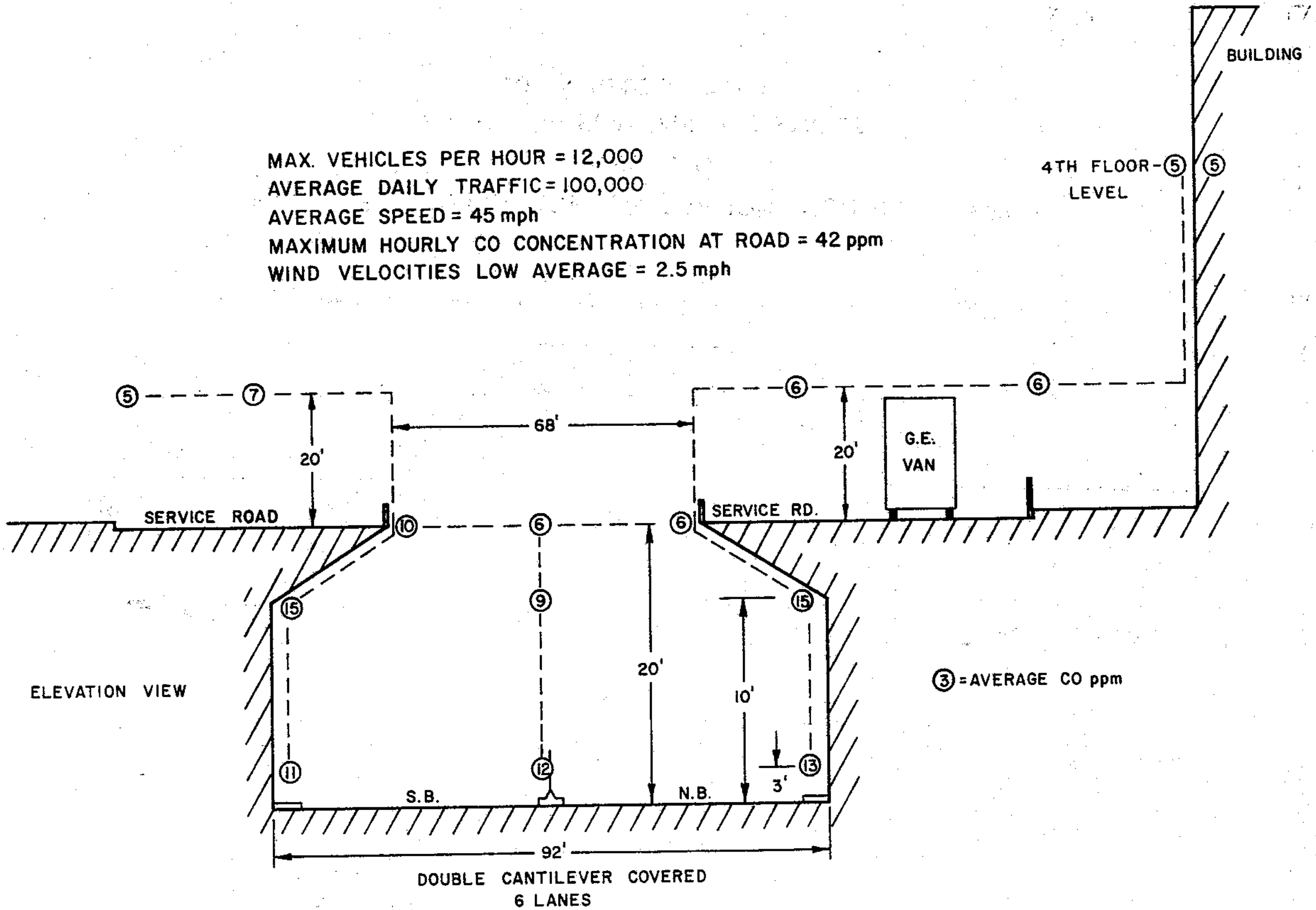


Figure 12 DISPERSION OF CARBON MONOXIDE FROM DOUBLE CANTILEVER COVERED ROAD

GRAND CENTRAL PARKWAY AT PARSONS BOULEVARD
NEW YORK STUDY

VEHICLES PER HOUR = 11,768
DATE = MAY 23, 1972
TIME = 1530 - 1630
WIND = 8 MPH
WIND ANGLE = 80°

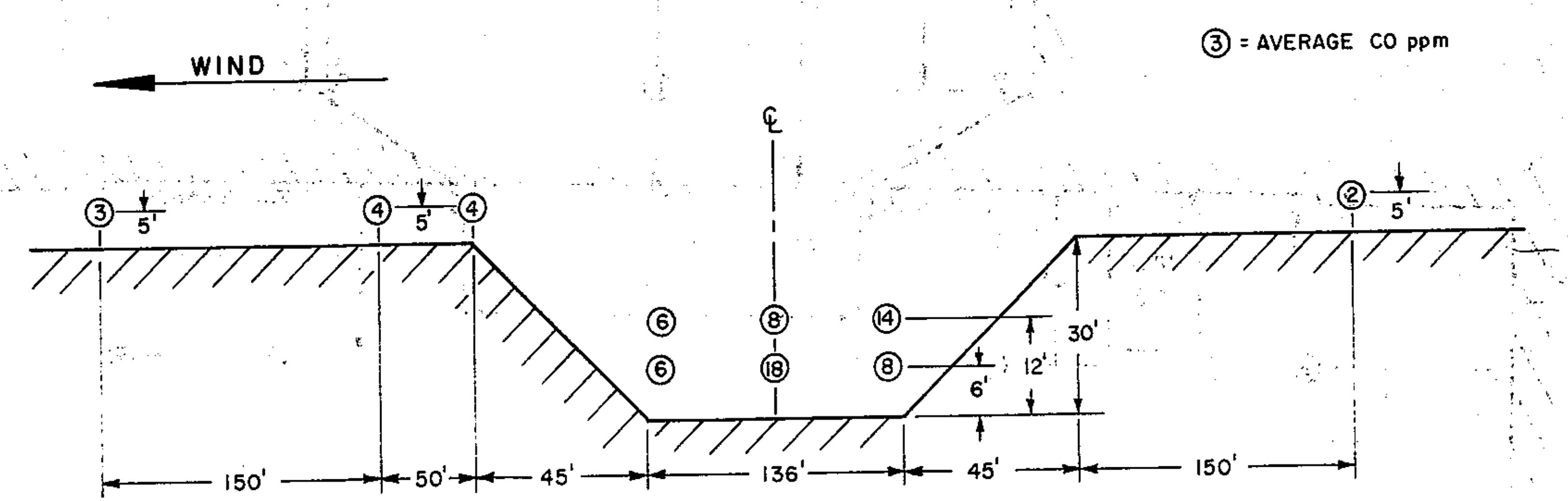


Figure 13 DISPERSION OF CARBON MONOXIDE FROM CUT SECTION

HARBOR FREEWAY AND 146 STREET
LOS ANGELES STUDY

VEHICLES PER HOUR = 10,100
DATE = OCTOBER 10, 1972
TIME = 1300
WIND SPEED = 7 mph
WIND ANGLE = 50°
FLAT, OPEN FETCH UPWIND AND DOWNWIND

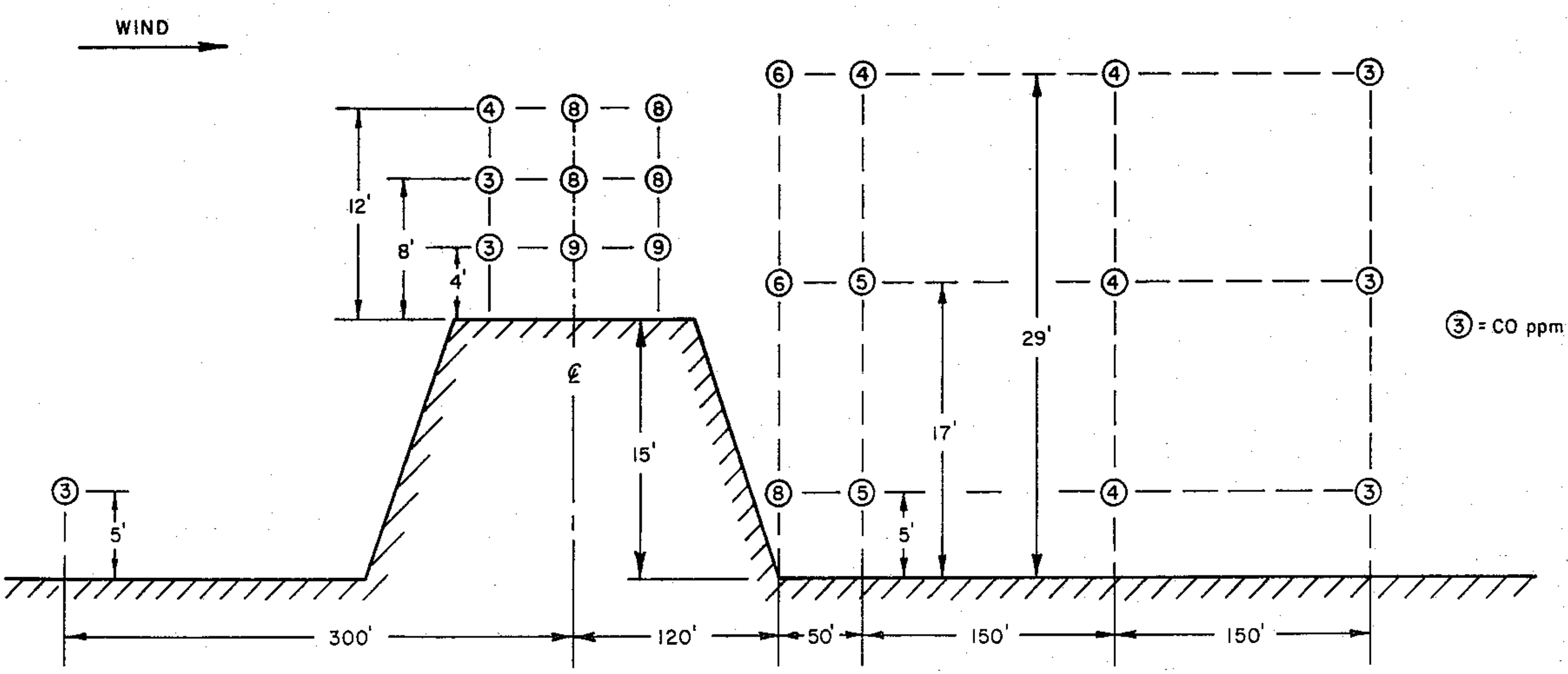


Fig. 14 DISPERSION OF CARBON MONOXIDE FROM A FILL SECTION
SAN DIEGO FWY. AT 122 ND ST.
LOS ANGELES STUDY

The primary emissions from a line source may be lifted from the corridor and coupled with other emission sources both stationary and mobile move over relatively long distances depending upon wind flow patterns within the basin. (A basin is an area outlined by air pollution experts as an area of common meteorological conditions).

During periods of favorable meteorological conditions, the emission load within the basin is adequately mixed and dispersed and no excessive concentrations of pollutants are noted. However, a period of unsatisfactory meteorological conditions, such as an inversion coupled with relatively stagnant conditions, may lead to a build up of primary emissions. During periods of intense sunlight, hydrocarbons and nitrogen dioxide enter into a series of chemical reactions under the influence of ultraviolet light. The various new compounds formed during such reactions are collectively called "smog". Some of these compounds may cause serious damage to certain agricultural crops.

It is presently virtually impossible to perform an analysis to determine the role played by the primary emissions from a specific line source in the photochemical changes leading to "smog" some miles downwind from the source. This will depend on the complex meteorology of the basin and the influence of topography on wind flow patterns. Again the building configuration, especially clusters of tall buildings, may influence wind flow patterns.

THE HIGHWAY ENGINEER AND AIR QUALITY

Planning and Design

The highway engineer must consider air quality during planning design, construction, and maintenance operations. If he is using operational concepts for traffic movement he should be aware of how this operation influences air quality.

The requirement that the highway engineer must furnish an Environmental Impact Statement for each of his projects during the planning and design stages requires a full discussion of the various possible environmental impacts including air quality.

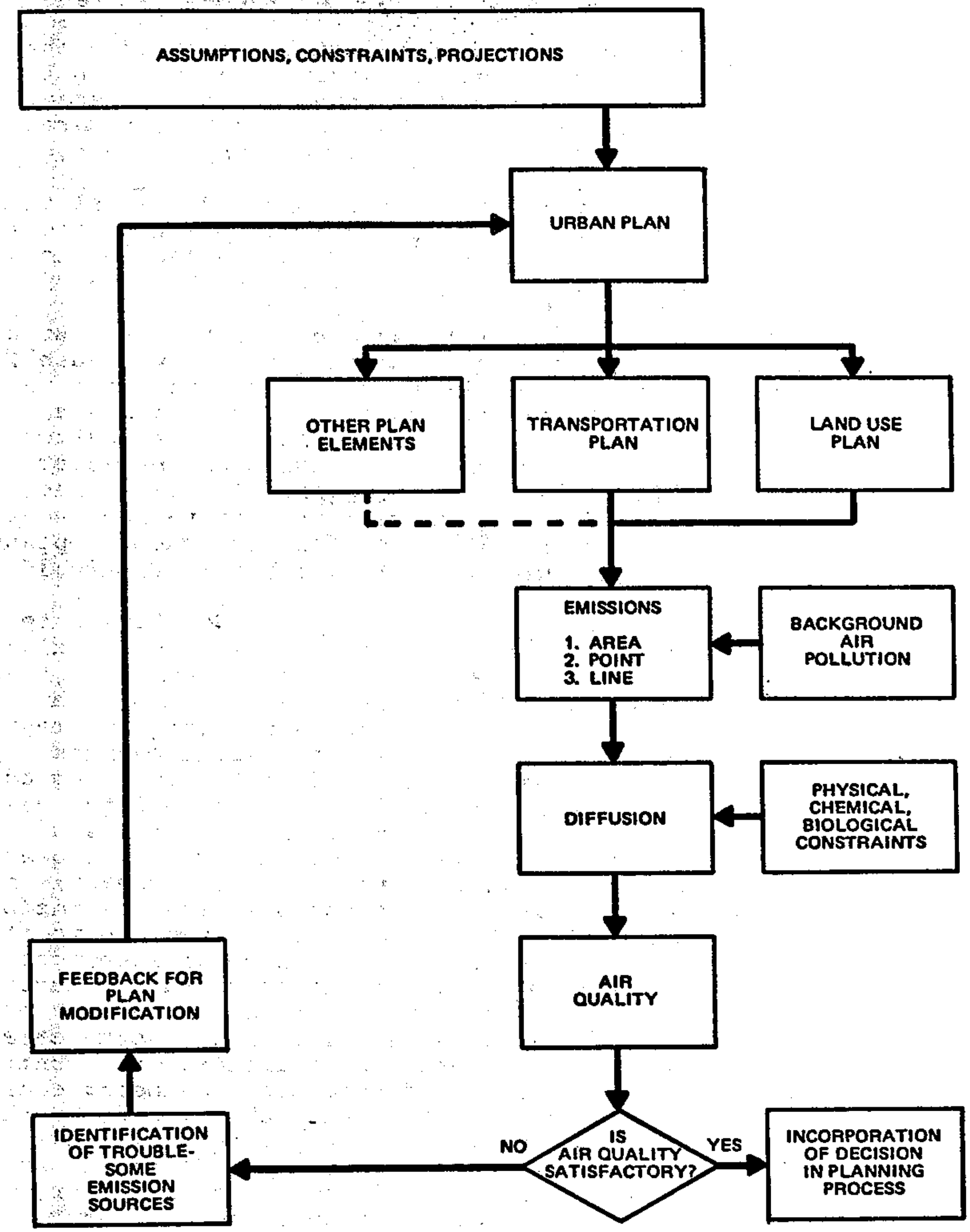
In order to properly evaluate the effect of the project on air quality, the highway engineer may hire a consultant to perform necessary field observations, analyze the results, and prepare a quantitative Air Quality Report. He also may develop the necessary staff for this purpose. A series of manuals [35] has been prepared to help technical groups prepare air quality reports for line sources. For general reading on this phase, reference [35f] of the manual series is recommended.

One of the purposes of the Air Quality report is to present information that will allow the writer of the Environmental Impact Statement to answer certain questions stated in the law. Some of these questions are directed to proposed implementation plans for the project that will overcome certain negative effects on the air environment. Also one must discuss the Federal Implementation Plan as related to the project. Another important consideration is the effect on air quality of not building the proposed project.

All of these questions require an understanding of the relationship between air quality and the project in terms of planning decisions and design criteria. Part of this has been presented in the previous discussion on the roadway and air quality.

References [36 through 44] should be studied for the various aspects of the problem in terms of planning and design. E. W. Hauser, et al [36] states, "Thus planners must have both long- and short-range views of emission problems due to transportation. The long-range view required involves two factors; the growth and changing patterns of transportation and the changing nature of emission characteristics of transportation, especially motor vehicles. The first factor is the chief one that lies in the purview of transportation and urban planners. However, the second factor must be included in planning." These considerations are shown in the flow chart in Figure 15 [41].

A series of examples found in Bellomo's paper [44] illustrate an analysis of advance planning in terms of air pollution. Existing urban systems may also be analyzed knowing the movement of traffic, average speed, and emission factors. From such data one may calculate the total tonnage of primary emissions into the region from the transportation network. The photochemical changes resulting from such an analysis is very difficult depending on many factors, especially meteorological parameters and the use of photochemical models which presently require further study and validation. The kinetics of the mechanisms involved have been under investigation to provide a basis for such models. However, the calculations of primary pollutants from various areas of the network will provide base information when proposals are made to modify the existing system. The modification of the system in some specific areas may lead to an improvement in traffic flow and a reduction in emissions for that area. Such a reduction in emissions may or may not cause a real reduction in photochemically modified material since the meteorological and topographic parameters will control the movement of the primary emission load from the area being considered. In this connection it is very important that the planner be thoroughly familiar with the meteorology and topography of the region involving the transportation system. This may be done either by consultation with air pollution specialists on the staff or by contacts with local, state, and federal air pollution experts.



igure 15 AIR QUALITY CONSIDERATIONS IN THE PLANNING PROCESS

From Reference (41)

As an example one may consider the proposed addition of a sizable length freeway to an existing system. The freeway will markedly change the existing street travel pattern for the specific area being considered in the planning process. As a first step, a complete traffic analysis must be prepared indicating all change in volumes and average route speed for the area influenced by the proposed freeway. Using emission factors and mix of vehicles one may calculate for the date of opening of the freeway the difference in emission tonnage. Now one must analyze the movement of this new emission load into other parts of the region if it is different than the existing road net within the area. In some cases the movement in a changed direction from a concentrated line source may definitely reduce the secondary pollutants formed by the photochemical process. On the other hand an increase may occur. Although of great complexity at present the planners must take definite steps to accumulate necessary data to make such an analysis possible in the near future.

In this connection the planner must also obtain from local or other air pollution agencies all available data on the locations and emission potential of all stationary sources within the region and within each area requiring analysis in connection with a proposal to modify the system. The gathering of a large volume of previously dispersed area traffic into a proposed line source to be located near a concentration of stationary sources may cause a high emission load which could cause serious problems in primary emission dispersion downwind of the complex or an increase in photochemical potential. This will of course depend on meteorological and topographic parameters.

Another very important problem in the regional urban planners consideration of air quality is the present concept of multimodal analysis for the transportation needs of a specified corridor. An example of this type analysis is found in Bellomo's paper [44]. In this analysis we have a very complex situation. One now must consider not only the freeway, but a number of other possible modes of travel either separately or in combination. As an example the traffic analysis necessary for air quality studies must be very complete for each proposed mode or combination in order to prepare an air quality comparison within the corridor. A proposal for rapid transit within the corridor would require a detailed realignment of the traffic patterns within the corridor including the starts and movements in and around the parking lots at the commuter stations. A different travel pattern would develop for a freeway alone or in combination with bus movements. In any case various emission factors would be required together with a detailed analysis of volumes, average route speed, and mix of cars and trucks. This must be projected for the maximum design life of the proposed facility in order to satisfy the requirements of the Environmental Impact Statement.

Following the system wide analysis and the influence of a new series of proposals within a specific area on the air quality of the basin, one must consider the effects on air quality within the corridor itself and within the immediate area. This will involve a microscale analysis in terms of meteorological and topographic parameters.

During the design stage the effect of the design on the air quality within the corridor (microscale) must be considered. Unfortunately, very little is known of the specific effects of depressed, elevated, and at grade sections, and other design features. As an example the location of a large complex distribution structure with its complex movements of concentrated masses of traffic may alter air quality within the immediate area since meteorological and topographic features may not be conducive for adequate mixing. Further research is required and a large scale effort in this direction is now underway in Los Angeles, California, where a cooperatively sponsored project by the Federal Highway Administration and the California Division of Highways will study the effect on air quality of different types of designs used for highways. The first information on this subject is contained in the recently released final report [33] on the studies in New York City.

Other forms of transportation such as mass transit within a corridor may also alter air movements in the same manner as highways through construction of necessary cuts and fills which may create a "reservoir" of air contaminants by disturbing low level currents which exist in a particular area. Further, the location of large parking lots at bus or rapid transit stations may markedly increase emission concentrations in the immediate area and downwind. This will require a thorough analysis for site selection since deceleration, acceleration, and idle modes are almost exclusive within and around such areas.

In a recent paper, Middleton and Ott [37] discuss air pollution and highway design. They state, "The present state of knowledge is not adequate to permit us to establish priorities for the individual design approaches that would minimize the pollution problem in all cases." However, examples of possible steps are the following:

1. Provide the maximum distance between routes and nearby dwelling places.

2. Provide the maximum width between traffic lanes consistent with safety.

3. Make dividing strips between opposing lanes as wide as possible.

S. Bellomo [44] also discusses some aspects of the design in relation to air quality.

Construction and Maintenance

Some construction and maintenance operations may alter air quality within the corridor and the immediate area. Dust and smoke are the two principal agents which may alter air quality during these operations. Highway Engineers should be familiar with all regulations relative to burning within each air pollution district and also all State laws in this connection. He should also be familiar with all regulations regarding dust discharges from not only on-site operations, but from the contractors activities at stationary plants involved with aggregate processing and the preparation of paving mixtures including asphalt and portland cement concrete.

In urban areas of some states rigid control of smoke and dust is maintained by local agencies on many types of industrial operations including those producing construction materials. In other areas the highway department may be required to issue their own specifications for control of dust and smoke emissions [45 and 46].

The curtailment of burning in connection with clearing operations may create new problems in disposal of the material. This may require burying within fills or hauling to some other location for disposal. A number of alternates are available [47] and should be studied by the engineer prior to start of construction. In fact the control of dust and smoke should be discussed in the Environmental Impact Statement during the design stage and be covered in the specifications for the project.

There continues to be a need for further research in this field especially on test methods for determining dust emissions from various operations of the contractor on the jobsite.

Operations

We have previously discussed the differences in emission levels from vehicles depending on the operating mode, idle, acceleration, deceleration, and cruise, and the fact that an improvement in operational characteristics will reduce emissions at least for two of the important pollutants, carbon monoxide and hydrocarbons. S. Bellomo [44] discusses this aspect of improvement of air quality by improving operational characteristics on city streets through the TOPICS program. Bellomo states, "Even though air pollution reduction is not one of the objectives of the program, it comes out as an important by-product of improved traffic flow. Such actions as synchronizing traffic signals and using computerized signal systems, improves traffic flow up to 30% and more, and a comparable decline in air pollution (carbon monoxide and hydrocarbons) can be expected for the operating systems. Unlike the effects of pollution reduction through planning and design of new development and facilities, pollution reductions on the operating system can affect the whole area." An excellent review on this and other aspects of transportation control is found in reference [48]. The application of such programs to freeways and expressways also shows promise of expediting traffic during high volume peaks by computerized ramp control and other methods. Such a system is under test at the present time on a freeway net in Los Angeles [49]. Such actions will reduce emissions by increasing the cruise mode of operation as Bellomo notes in his paper [44].

THE FUTURE

Acting Federal Highway Administrator, Ralph R. Bartelsmeyer, in an address before the 1972 Convention, Association of Highway Officials of North Atlantic States [50], states, "State highway officials today are very involved in environmental matters - probably more so than many of their critics -- and they are going to remain involved for the foreseeable future. But I want to emphasize that State highway officials have always been interested in the environment and the ecology. Their involvement is more intensified today."

The many factors involved in the effects on air quality of transportation systems requires a large scale future research effort. The present state of knowledge does not provide answers for many very important questions. Emission factors for motor vehicles are still open to question. Even the simplest mathematical models have not been properly validated. Very little is known on the accuracy of photochemical models. The proper deployment of meteorological equipment and analysis of data for the many line source situations encountered in the United States awaits solution.

The highway administrator should fully realize the complexity of the air quality problem and proceed on the basis of fostering active research in the field together with the development of specialists within his own organization. He should be cognizant of other Federal and State agencies involved in the field and establish working relationships with key personnel in these agencies.

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